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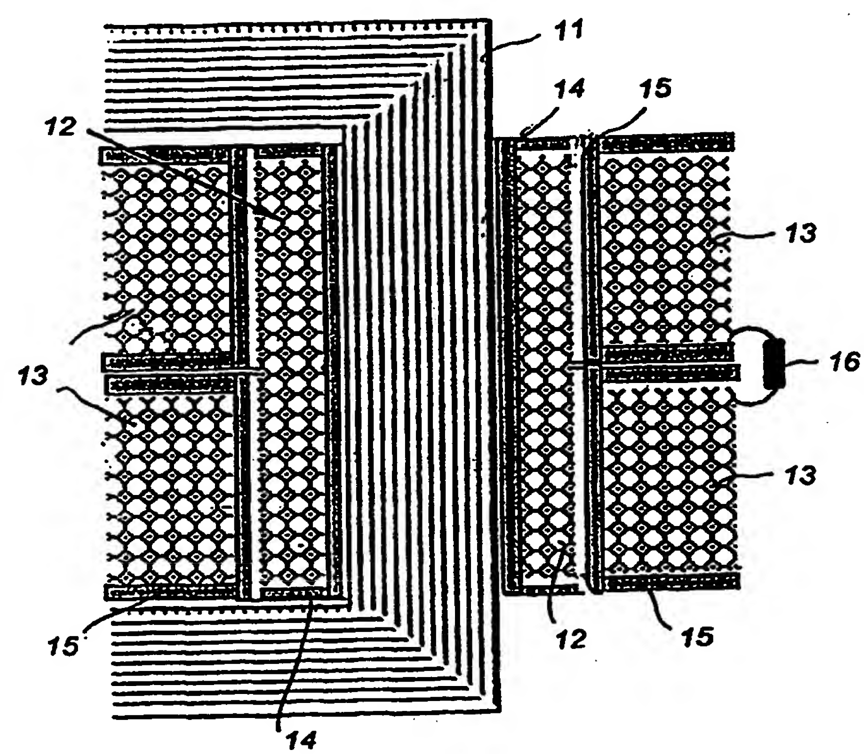
(54) Title: A WINDING IN AN ELECTRIC MACHINE WITH STATIONARY PARTS

(57) Abstract

A winding (13) in an electric machine with stationary parts consists of high-voltage cable (1) and is in the form of prefabricated drums (15) onto which the cable (1) forming the winding is wound. The drums (15) are mounted in the machine on site.



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A WINDING IN AN ELECTRIC MACHINE WITH STATIONARY PARTS

The present invention relates to a winding as stated in the preamble of claim 1 in an electric machine with stationary parts, e.g. a power transformer, intended for use at high voltages, by which is meant primarily electric voltages exceeding 10 kV. A typical working range for a transformer according to the invention may be 36-800 kV.

Conventional power transformers have, as disclosed e.g. in the book "Elektriska Maskiner" by Fredrik Gustavson, Page 3.6 - 3.12, Kungliga Tekniska Högskolan, 1996, usually been cooled and insulated by oil. However, a number of problems are inherent in such oil-filled power transformers. An outer housing is required for the transformer with a transformer core with windings, oil for insulation and cooling, and mechanical bracing means of various types. The mechanical demands placed on this housing are considerable and the manufacturing and assembly processes are extremely time-consuming. Finally, the external dimensions of the housing are large, thus entailing transport problems. Oil-cooling, particularly pressurized oil-cooling, also requires access to oil pumps, external cooling elements and expansion vessels, etc. The insulating material must also be extremely pure and freely from conducting particles. The moisture content in both the oil and other insulating material must also be far below that of the atmosphere. In normal production the moisture content in separate processes is reduced to values below 1 % for paper and other cellulose materials and a few microparts in the oil. The whole insulation system must be carefully dried at the end of the manufacturing pro-

cess. This high degree of purity and low moisture content must be maintained during transport and operation of the transformer.

Through e.g. JP 4 179 107, JP 6 196 343, and JP 7 057 951 a winding in the form of prefabricated drums is previously known. However, such a winding has not been used with high-voltage cables.

A conductor is known through US 5,036,165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US 5,066,881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

The object of the present invention is to solve the above problems and further improve such machines by simplifying manufacture, facilitating transport and reducing manufacturing and assembly costs. This object is achieved in that the machine according to the invention is given the features defined in the characterizing portion of claim 1.

The invention is primarily intended for use, and its advantages are particularly apparent, with a high-voltage cable of the type built up of a core having a

plurality of strands, an inner semi-conducting layer surrounding the core, an insulating layer surrounding the inner semi-conducting layer and an outer semi-conducting layer surrounding the insulating layer. More particularly it relates to such a cable with a diameter in the range of 20-200 mm and a conducting area in the range of 80-3000 mm^2. Such applications of the invention thus constitute preferred embodiments.

In the arrangement according to the invention the windings are preferably of a type corresponding to cables with solid, extruded insulation, such as those used nowadays for power distribution, e.g. XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to

layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa.

The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at le-

ast of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently great to enclose the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface and the winding, with these layers, will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The invention will now be described in more detail with reference to the accompanying drawings in which

Figure 1 shows a schematic section through one phase of a power transformer according to the invention and

Figure 2 shows a cross section through a winding cable used in the transformer according to the invention.

Figure 1 shows a part of a power transformer in section, having a transformer core 11, a low-voltage winding 12 and a high-voltage winding 13. According to the invention the windings are wound onto prefabricated drums 14 and 15. These drums are completely wound at

the factory and then transported to the site where the transformer is to be used, where they are a mounted on respective phases of the core (only one phase of the transformer is shown in Figure 1).

In the example shown in Figure 1 the high-voltage winding 13 is divided into two drums 15 for manufacturing and transport reasons. When the winding is divided into several drums the cables in the individual windings are connected by a cable joint 16 on site.

Figure 2 shows a section through a power cable 1 for use in a dry power transformer according to the present invention. The cable 1 comprises a number of strands 2 consisting of a conductor made of copper, for instance, having circular cross section. This conductor is arranged in the middle of the cable 1. Around the cable is a first semi-conducting layer 3. Around the first semi-conducting layer 3 is an insulating layer 4, e.g. XLPE insulation. Around the insulating layer 4 is a second semi-conducting layer 5. In this case, therefore the cable does not include the outer sheath that normally surrounds such cables for power distribution. The cable may be of the size stated in the introduction.

Tubes or ducts for cooling air are arranged between the winding cables to cool the winding in the transformer according to the present invention. These tubes or ducts are suitably arranged in the drums 14 and 15 at manufacture before the transformer is transported to where it is to be used.

Thanks to the invention a dry power transformer is achieved which is simpler to manufacture than conventional transformers. The transformer need not be transported as a unit from factory to site, and both transport and assembly become less expensive.

The invention is of course not limited to a power transformer but is also applicable to other electrical machines with stationary parts, such as inductive reactors.

CLAIMS

1. A winding in an electric machine with stationary parts, the windings being in the form of prefabricated drums (15) onto which the conductor (1) forming the winding is wound, said drums (15) being mounted in the machine on site, **characterized** in that the winding (13) consists of high-voltage cable (1).

2. A winding as claimed in claim 1, **characterized** in that the high-voltage cable (1) comprises a core (2) with a plurality of strands, an inner semi-conducting layer (3) surrounding the core (2), an insulating layer (4) surrounding the inner semi-conducting layer and an outer semi-conducting layer (5) surrounding the insulating layer.

3. A winding as claimed in claim 2, **characterized** in that the high-voltage cable (1) has a diameter in the range of 20-200 mm and a conducting area in the range of 80-3000 mm^2.

4. A winding as claimed in any of claims 1-3, wherein the machine constitutes a power transformer having a core (11) with low-voltage and high-voltage cables (12, 13) surrounding the core **characterized** in that the windings (12, 13) are in the form of prefabricated drums (14, 15) onto which the cable (1) forming the windings (12, 13) is wound, said drums (14, 15) being mounted on the transformer core (11) at the site where the transformer is to be used.

5. A winding as claimed in claim 4 **characterized** in that the high-voltage coil (13) is divided into a number of drums (15) for each phase, cable joints (16) between the drums (15) being applied during assembly on site.

6. A winding as claimed in claim 1 or 2 **characterized** in that tubes or ducts for cooling the windings (12, 13) are arranged in the drums (14, 15) at manufacture before, they are transported to the site where the transformer is to be used.

7. A power transformer **characterized** by a winding as claimed in any of claims 1-6.

8. An inductive reactor **characterized** by a winding as claimed in any of claims 1-6.

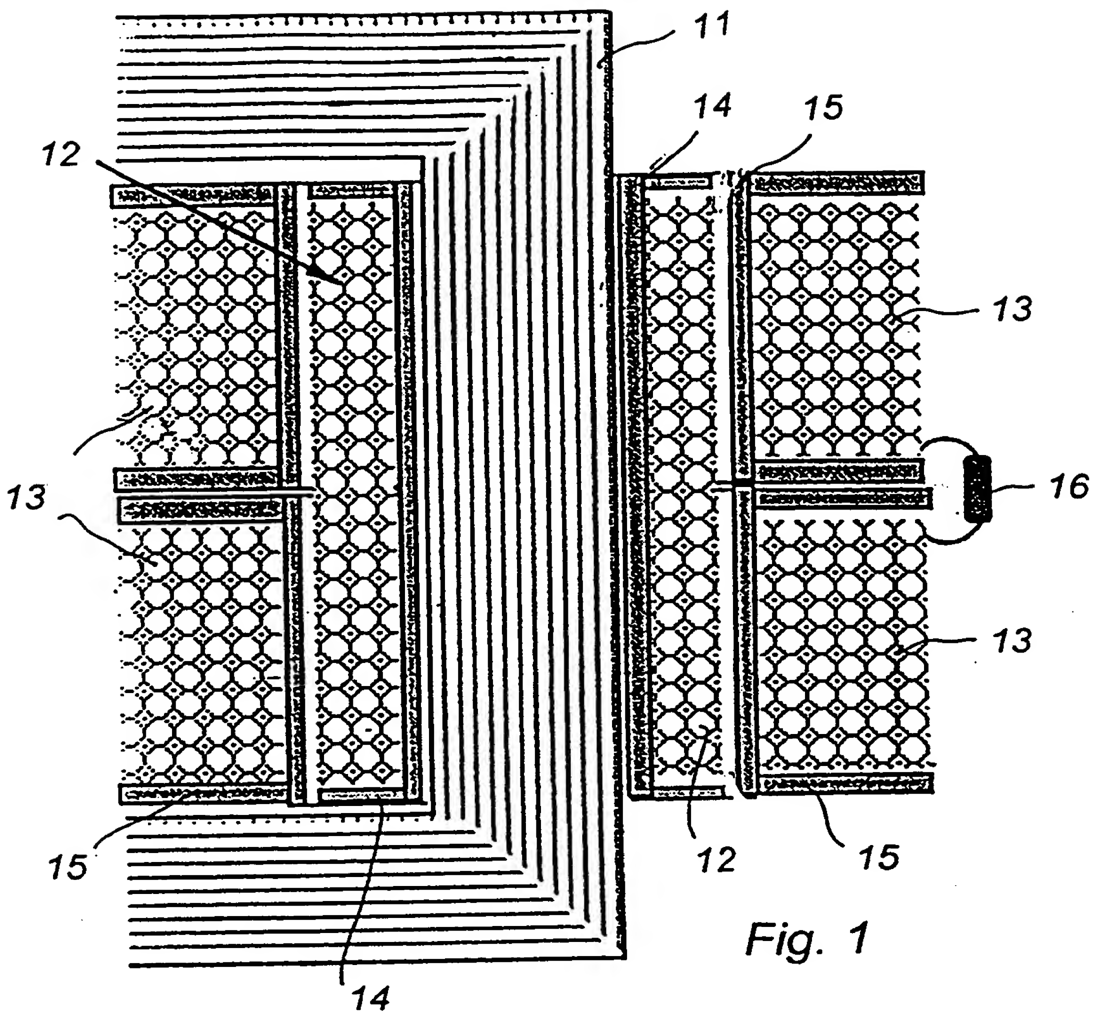

Fig. 1

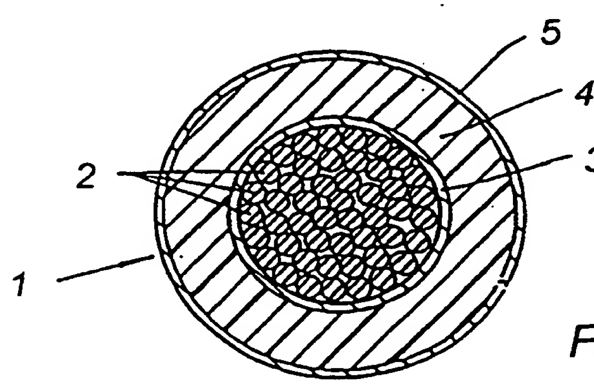

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00157

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01F 41/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EDOC, WPIL, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Patent Abstracts of Japan, abstract of JP 41-79107 A (TOSHIBA CORP), 25 June 1992 (25.06.92) --	1,4-8
X	Patent Abstracts of Japan, abstract of JP 61-96343 A (TOSHIBA CORP), 15 July 1994 (15.07.94) --	1,4-8
X	Patent Abstracts of Japan, abstract of JP 70-57951 A (TOSHIBA CORP), 3 March 1995 (03.03.95) --	1,4-8
A	US 5036165 A (RICHARD K. ELTON ET AL), 30 July 1991 (30.07.91), abstract -- --------	2,3

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

29/04/98

International application No.
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5036165 A	30/07/91	US 5066881 A	19/11/91
		US 5067046 A	19/11/91
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